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THE IMPACT OF WINDS-ALOFT ERRORS ON AIR-TO-GROUND BALLISTIC ORDNANCE DELIVERIES

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This report presents a procedure for estimating how errors in upper-wind information affect bombing accuracy in normal delivery of ballistic ordnance. The procedure resulted from an analysis of on-site pibal support to the Tactical Air Command (TAC) ground attack training program.

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THE IMPACT OF WINDS-ALOFT ERRORS
ON AIR-TO-GROUND BALLISTIC ORDNANCE DELIVERIES

1. General

This report presents a procedure for estimating the degree to which bombing accuracy (for the normal delivery of ballistic ordnance) is influenced by errors in wind information. The procedure resulted from an analysis of on-site pibal support to the Tactical Air Command (TAC) ground attack training program. It provides a useful tool for cost effectiveness calculations and can help to define more clearly the decrease in bombing accuracy to be expected in a combat environment where real-time wind observations are not available.

The approach employed is to estimate, for specific delivery maneuvers, the impact of winds-aloft information on known bombing accuracy. Only manual ballistic ordnance deliveries are analyzed since the effect of wind data errors on automated delivery systems (such as that used on the F-111) is small by comparison.

Recommendations on the type of wind information required for specific situations are not presented. Rather, this report provides a methodology that will assist in making such determinations. Statistical data on actual bombing accuracies achieved in training for mission ready (MR) mission capable (MC) aircrews are maintained by each TAC wing. This report would make it possible to calculate the expected change in bombing accuracy when using other sources for wind information, e.g., forecast winds instead of observed pibal winds.

Three inputs are required to apply the methodology: (a) actual bombing accuracy data for a particular weapon type and delivery maneuver; (b) the accuracy of winds-aloft information provided to aircrews when the bombing accuracy data were generated; and (c) the type and accuracy of alternative sources of winds-aloft information. The result of the calculations with these inputs is an estimate of bombing accuracy that would be realized when the winds-aloft information of a differing accuracy is used.

2. Expected Changes in Bombing Accuracy

Measures of bombing accuracy for each of the basic air-to-ground weapons delivery techniques are the circular error (CE), circular error average (CEA), and circular error probable (CEP). The latter two are statistical measures based on actual bombing data over an extended period of time and are computed and maintained for individual aircrews, squadrons, or wings. The CEA is the average of the bombing errors (for a particular maneuver) given by

$$\mathrm{CEA} = \frac{1}{N} \sum_{i=1}^{N} \mathrm{CE}_i \qquad (1)$$

where N = Number of record deliveries*

CE = Circular error* of the ith record delivery (in feet)

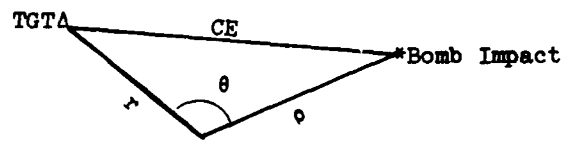
The CEP is the median of the distribution of CEs, i.e., 50 percent of the CEs are greater than the CEP. If the distribution of CE is circular normal, then the CEP may be estimated from the CEA by

$$CEP \simeq 0.939\ CEA$$

With this relationship in mind, it is necessary to investigate only the parameter CEA. The approach presented here parallels that used in an earlier study on this same subject by Ellsaesser [1]. On any single record delivery, the CE is assumed to be the resultant of two component errors: (a) a component (ρ) due to an error in wind information; and (b) a component (r) due to all other causes. Additionally, it is assumed that these component errors are independent. The relationship between CE, ρ, and r is given by

$$CE = +(\rho^2 + r^2 - 2\rho\ r \cos\ \theta)^{\frac{1}{2}} \qquad (2)$$

where θ is the angle between the two component errors. With the stated assumptions, the following relationship can be derived (Appendix A)



$$CEA_2 = +\left[CEA_1^2 + \frac{E^2}{1.273}\,\Delta(\sigma^2)\right]^{\frac{1}{2}} \qquad (3)$$

where $\Delta(\sigma^2) = \sigma_2^2 - \sigma_1^2$

σ_1, σ_2 = Root mean square vector wind errors (knots) for two different sets of wind information with differing accuracies.

E = Wind bombing error factor; feet of bomb error per knot of wind error, where wind error is the absolute value of the vector difference between the planning wind and the actual wind.

CEA_1 = Circular error average achieved when wind data of accuracy σ_1 were provided to aircrews.

CEA_2 = Circular error average expected if wind data of accuracy σ_2 are provided.

Initial CEAs (CEA_1) can be computed from AF Forms 107, Weapons Delivery Qualification Records. What remains is to determine the factors E and $\Delta(\sigma^2)$. These factors are discussed in paragraphs 3 and 4.

Figures 1 through 5 show the relationship between the expected change in CEA (i.e., $\Delta CEA = CEA_2 - CEA_1$), E and $\Delta(\sigma^2)$ for CEA = 100, 200, 300, 400, and 500 feet. These diagrams (or the original equation) can be used to provide estimates of the change in bombing accuracy that would result if an alternative method for providing ballistic wind data is employed.

* as defined in AFR 55-89 [5].

3. <u>Calculation of Feet of Bomb Error Per Knot of Wind Error - The Parameter E</u>

a. <u>Assumptions</u>. The primary practice munitions used at TAC gunnery ranges are: (1) the BDU-33 series (low drag); and (2) the MK-106 (high drag). The effect of an error in planning winds (for an individual delivery) on these practice munitions is presented below. A wind error is defined as the absolute value of the vector difference (in knots) of the winds aloft provided to aircrews and the actual winds aloft encountered during the weapon delivery. The analysis is confined to the following weapons delivery events: (1) low angle bombing (LAB) using the MK-106; and (2) dive bombing (DB) and high altitude dive bombing (HADB) using the BDU-33. These are manual ballistic ordnance deliveries and, except for skip bombing, represent all of the manual deliveries addressed in AFR 55-89 [5], Tactical Fighter Weapons Delivery Qualification, that have any substantial wind sensitivity.

The effect of wind errors on semi- and fully-automated delivery systems (e.g., dive toss using the weapons release computer set (WRCS)) for ballistic munitions is considerably less than for manual deliveries. For manual ballistic deliveries the following assumptions are maae (refer to TAC Ground Attack Phase Manual USAF Operational Training Course - F-4, Nov 74 [6], T.O. 1F-4C-34-1-1, Sections I and IV [7]).

(1) The primary consideration in making accurate DB and HADB deliveries is the altitude of the aircraft above ground level (AGL).

(2) The primary consideration in making accurate LAB deliveries is the horizontal range to the target.

(3) The primary technique used to compensate for wind effects on DB and HADB deliveries is the fully-drifting technique.

(4) The primary technique used to compensate for wind effects on LAB deliveries is the crabbing approach technique.

(5) There is no wind shear in the vertical.

(6) From rollout on final run-in to bomb release, the pilot flies the delivery according to the planned wind information and does not take corrective action when the actual winds are found to be different. The degree to which pilots can, and do correct for wind errors is variable, depending on individual pilot skill, training, and techniques to correct for such wind errors (e.g., early release, late release, etc.). It is safe to assume that the real-life errors due to wind inaccuracies will be less than those experienced when the pilot takes no corrective action after rollout on final approach to the target.

b. <u>Assumed Delivery Technique</u>

(1) Fully-drifting (DB and HADB). In this delivery method, the pilot rolls out wings level, on final approach at an altitude determined to allow for tracking time (t_r) prior to release altitude. Initial pipper placement (using the combat offset technique) is achieved at this time at a distance of $(t_c+t_r/t_c) \times (AOD)$ into the forecast wind, where t_c is the bomb time of fall in seconds and the AOD is the aim-off distance; AOD = 1.69 (t_c) x (wind speed in knots). The pilot maintains

correct release parameters (airspeed, dive angle, etc.) for t_r seconds and releases the bomb at the planned release altitude after which the bomb falls for t_c seconds before it impacts the ground.

During the approach, an aircraft heading parallel to the planned run-in heading is maintained. The tracking times used for this analysis are: (1) t_r = 10 seconds; and (2) t_r = 5 seconds (which simulates a tactical delivery). The bombing error (in feet) for each knot of wind error is given by

$$E = 1.69\ (t_r + t_c)$$

where E is the wind bombing error factor. Range-wind and crosswind errors are combined in the above expression since wind errors are expressed in terms of the absolute value of the vector difference between planned and actual winds. Values of t_c are provided in the T.O. 1F-4C-34-1-2 ballistic tables [8].

(2) Crabbing Approach. Level delivery (dive angle ≃ 0°). The pilot rolls out on the final approach to the target and applies enough crab into the actual wind to maintain the planned ground track using planned winds. This ground track is offset by an amount based on the planned cross winds relative to the run-in heading. The ground track is flown until the pipper (using a depressed sight setting) crosses a line which passes through the target and is perpendicular to the planned ground track. The bombing error (in feet) due to each knot of wind error is given by Appendix B

$$E = +\left(2.86\ t_c^2 - \frac{1.69\ R_3\ t_c}{V_A} + \frac{R_3^2}{2V_A^2}\right)^{\frac{1}{2}} \tag{4}$$

where t_c = bomb time of fall in seconds

R_3 = bomb range in feet (horizontal distance between release and impact points)

V_A = aircraft true airspeed in knots

Values of t_c, R_3, and V_A are provided in the T.O. 1F-4C-34-1-2 ballistic tables [8].

c. Error Analysis. The contribution of wind errors to bombing errors under the assumed delivery techniques are provided in graphical form in Figures 6 through 14 (using data provided in the ballistic tables). The bombing errors are given in terms of feet of bomb error per knot of wind error (E, wind bombing error factor). For the low-drag practice bomb (BDU-33 series), errors are presented as a function of release altitude (H) and dive angle (θ) for true airspeeds (TAS) of 400 and 600 knots and tracking times of 5 seconds and 10 seconds.

The analysis results for bomb release using a multiple ejector rack/triple ejector rack (MER/TER) are shown in Figures 6 through 9, and for the SUU-20 disperser pod in Figures 10 through 13. Ballistic data for the SUU-21 pod are similar enough to the SUU-20 for analysis purposes to be considered the same, and errors using the SUU-21 are not shown. In fact, the differences between the MER/TER and SUU-20 error

graphs is insignificant in comparison with the range of errors due to other factors (i.e., H, θ, TAS, t_c). The error analysis for high-drag deliveries (MK-106 practice bomb) is shown in Figure 14 as a function of release altitude (H) and true airspeed (TAS). For dive angles up to 15 degrees, the analysis is nearly identical and only the 0-degree (level flight) delivery is shown. The wind bombing error factors (E) derived from these charts are used in determining the expected change in CEA.

4. Estimation of the Root Mean Square Vector Wind Error - The Parameter σ

To determine an expected change in CEA, an estimate of the accuracy of current wind information (employed in the training which generated the CEA_1 data) is required, as well as the accuracy of wind information in a proposed alternative method for providing winds-aloft support. The required measure of accuracy for this study is the root mean square error (RMSE), a statistical wind variability measure based on the historical differences between observed or forecast winds aloft and the actual winds aloft. Methods for estimating the RMSE for pilot balloon and forecast winds-aloft methods are provided below.

a. Pilot Balloon Support. For pibal observations the RMSE is a function of the following factors

(1) Factor 1: the age of the wind information.

(2) Factor 2: the distance between the point at which the pibal observation is taken and where the information is applied.

(3) Factor 3: the inherent accuracy of the pibal observation system itself.

(4) Factor 4: the general geographic location for which the information applies.

Factors 1 and 4 can be considered jointly by the following expression [3]

$$\sigma_t = 0.2\ \sigma t^{\frac{1}{2}} \qquad \tfrac{1}{2}\text{ hr} < t < 24\text{ hrs} \tag{5}$$

where σ_t = Wind RMSE due to time lag (knots)

σ = Climatological RMSE, as a function of geographic location and altitude (knots)

t = Time lag (age) of the wind information (hours)

Values of σ (by season and standard atmospheric pressure level) are provided in 3 WWM 105-5 [9]. Annual values are listed in Table 1 for the 850-mb level (approximately 5000 feet MSL) for selected TAC controlled air-to-ground gunnery ranges.

A more precise relation for σ_t is given by [4]

$$\sigma_t = \sigma\ \{2[1 - \exp(-0.0248t)]\}^{\frac{1}{2}} \tag{6}$$

However, the first expression for σ_t is within 8 percent of the latter for time lags up to 6 hours, and will be used in this analysis. Factor 2, wind variability due to distance, is given by the following expression [4]

$$\sigma_d = 1.3\ d^{\frac{1}{2}} \tag{7}$$

Table 1. Annual Climatological Wind Variability at the 850-mb Level (RMSE) for TAC Gunnery Ranges.

Range	Controlled by	850-mb Annual RMSE (knots)
Avon Park	MacDill AFB	14
Claiborne	England AFB	18
Cuddeback Lake	George AFB	13
Dare County	Seymour-Johnson AFB	18
Luke	Luke AFB	11
Melrose	Cannon AFB	14
Oscura	Holloman AFB	13
Poinsett	Shaw AFB	18
Saylor Creek	Mountain Home AFB	12
Nellis	Nellis AFB	12

where σ_d = root mean square wind distance variability error (knots)

d = distance from the location of wind information (statute miles)

Factor 3, the inherent accuracy of the pibal observing system is denoted by σ_e: the inherent root mean square error of the system (knots). Routinely, wind information for TAC gunnery ranges is provided by a single theodolite pilot balloon. The inherent error of this equipment (at least for wind observations below 10,000 feet MSL) is given by [1]

$$\sigma_e = 2.5 \text{ knots} \tag{8}$$

For this analysis, the statistical measures of error (σ_t, σ_d, and σ_e) will be considered to be <u>independent</u>. Consequently, the total RMSE for wind variability is determined by

$$\sigma_T = +(\sigma_t^2 + \sigma_d^2 + \sigma_e^2)^{\frac{1}{2}} \tag{9}$$

Since TAC air-to-ground gunnery ranges are supported primarily by single theodolite pilot balloons, one need only to estimate σ_t and σ_d in order to determine the accuracy of wind information under current local methods of support. The distance variability parameter, σ_d, is readily determined by knowledge of the distance of the pibal observation site relative to the gunnery range complex (target scoring area(s)). However, σ_t is not as readily determined. For this time-lag error determination, the <u>mean age</u> of the wind data must be determined. For this purpose, assume a minimum time lag, t_m, of $\frac{1}{2}$ hour (i.e., the time required to operate the pilot balloon equipment, perform all required computations, transmit the data to the user, and the time delay from when the aircrew receives the data to when the weapon delivery is accomplished). The data will be <u>at least</u> this old. The periodicity, t_f, of pibal observations determines the maximum age of the wind data to be $t_m + t_f$. If we assume that aircrews receive and use this information at random times throughout the day, then the mean age of pibal data is given by

$$\bar{t} = t_m + \frac{t_f}{2} \qquad (10)$$

b. Computer Model Forecast Winds-Aloft Support. Due to the nature of how computer model forecast winds aloft are produced and transmitted, a timing error must be considered. Presently, mathematical computer-driven models of the atmosphere rely primarily on sounding data acquired simultaneously at 0000Z and 1200Z, worldwide, on a daily basis. Forecast 3-dimensional wind fields are output from these models at specified valid times relative to the time of the observed data base (e.g., 3 hour, 6 hour, 12 hour, etc.). However, current models have the capability to produce these forecast fields at least every hour (e.g., valid times of 6 hour, 7 hour, 8 hour, etc.).

When considering these forecast winds as a possible alternative to pibal-derived winds, the 1-hour interval between valid forecast times should be used to determine timing error. With a tailored support of 1 hour between valid times, an aircrew will not be more than 30 minutes from any forecast valid time. If sorties are assumed to occur at random relative to these valid times, then the mean timing error is 15 minutes and a sortie may lead as well as lag a particular valid time. Consequently, the time variability for computer-generated winds-aloft forecasts is given by

$$\sigma_t = 0.2\ \sigma t^{\frac{1}{2}} = 0.2\ \sigma(\tfrac{1}{4})^{\frac{1}{2}} = 0.1\ \sigma \qquad (11)$$

Even though this expression has a lower limit of $t = \frac{1}{2}$ hour, results obtained using $t = \frac{1}{4}$ hour are likely to be of sufficient accuracy for use in this analysis.

Using the above expression to determine σ_t requires that σ_e for the forecast system be estimated. The parameter σ_d is not required since the location of the forecast winds can be tailored to coincide exactly with the location of scored gunnery ranges. The Air Force Global Weather Central (AFGWC) utilizes a $\frac{1}{2}$-mesh boundary layer model to produce forecast winds aloft (surface to 1600 meters AGL) for the United States, Europe, and Asia. AFGWC has computed RMSE statistics from this boundary layer model for each of the above three regions. These values are listed in Table 2 for the three operational theaters at the 1600-meter AGL level (roughly equavalent to the 850-mb standard pressure level, about 5000-feet MSL), and at valid times of 12 and 24 hours. The statistics are derived from data collected over a 2-year period (1974-1976) and sample sizes are listed for each RMSE.

The AFGWC RMSE statistics were derived by taking the difference between a forecast wind, for a particular level, and comparing it to the actual winds observed at a rawinsonde location. The instrument error of the rawinsonde system is approximately 1-knot root mean square vector error [1]. Again, assuming that this error is independent of the forecast wind error, this instrument error of 1 knot must be added (in a statistical sense) to the values listed in Table 2 to provide an overall σ_e for computer-derived forecast winds aloft at the 12- and 24-hour valid times. That is, the square of the values in Table 2 plus 1 knot^2 equals the square of the overall σ_e.

Table 2. Annual Forecast Winds-Aloft Forecast Error Statistics (RMSE) for the AFGWC ½-Mesh Boundary Layer Model at 1600 Meters (AGL). Period of Record: 1974-1976, sample sizes indicated.

	Forecast Valid-Time/Sample Sizes	
Theater	12-Hour Sample Size	24-Hour Sample Size
United States	7.6 knots/3972	8.8 knots/4150
Europe	7.3 knots/4728	8.4 knots/4144
Asia	7.3 knots/4829	8.5 knots/4644

In order to estimate σ_e for other valid times, linear interpolation/extrapolation can be used with sufficient accuracy for valid times between 4 hours and 24 hours. Valid times less than 4 hours need not be considered since the time required to collect the initial upper-air data base, process the data via a numerical computer model, and to transmit the forecast wind data to the aircrew requires approximately 4 hours. Consequently, if forecast winds are to be used to support TAC air-to-ground training, aircrews will use forecast winds aloft with valid times anywhere from 4 hours to 16 hours due to the 12-hour upper-air observation frequency (i.e., valid times from 0400Z to 1600Z and from 1600Z to 0400Z).

Another consideration in determining σ_e is how the daily training schedule aligns itself with the minimum available times of the forecast wind data (i.e., 0400Z and 1600Z). For daylight training in the United States, the daily training schedule can be broken into two periods: that prior to 1600Z; and that after this time. The period prior to 1600Z must use forecast winds based on the previous 0000Z data base time. For each of these two periods, the mid-point forecast valid time is then determined. The σ_e values corresponding to these mid-point times is found by linear interpolation/extrapolation from Table 2. Figure 15 (which includes the 1-knot RMSE of the rawinsonde observations), can be used for this purpose. These values are then combined by taking a weighted average (based on the proportions of the total daily training period of each of the two defined training periods). The following exemplifies this procedure for estimating σ_e for forecast winds-aloft support.

Assume that the daily training period is from 1200Z to 2200Z. The first period is from 1200Z to 1600Z (4 hours) and the second from 1600Z to 2200Z (6 hours). The mid-point forecast valid time of the first period is 1400Z and for the second period, 1900Z. From Figure 15, for the United States, σ_e for the first period is 7.85 knots (14-hour valid time) and 7.15 knots (7-hour valid time) for the second period. The overall estimate of σ_e in this situation is found by

$$\sigma_e = \frac{T_1}{T}\,\sigma_{e1} + \frac{T_2}{T}\,\sigma_{e2} \qquad (12)$$

where T_1 = First period interval (4 hours)

T_2 = $T_1 + T_2$ = Total training period interval (10 hours)

σ_{e1} = First period mid-point RMSE (7.85 knots)

σ_{e2} = Second period mid-point RMSE (7.15 knots)

then

$$\sigma_e = 4/10\ (7.85\ \text{knots}) + 6/10\ (7.15\ \text{knots})$$

$$\sigma_e = 7.43\ \text{knots}$$

5. Determination of the Expected Change in the Mean Bombing Accuracy - Examples

From paragraph 2, in order to determine the expected change in the CEA, values of CEA_1, E, and $\Delta(\sigma^2)$ must be known. CEA_1 is determined from aircrew training records and paragraphs 3 and 4 describe the means to determine (or estimate) values of E and $\Delta(\sigma^2)$ for various scenarios. Two examples are provided below which determine ΔCEA under different hypothetical situations.

a. Example 1. Consider the Cuddeback Lake air-to-ground range in southern California which is controlled by the 35th Tactical Fighter Wing (TFW) at George AFB. Pilot balloon observations of winds aloft are accomplished every 2 hours ($t_f = 2$) during training periods. The site of these observations is approximately ½ mile from the target complex on the range ($d = \frac{1}{2}$). Over the past year assume that the circular error average of the TFW using Cuddeback Lake for training is 300 feet for HADB tactical deliveries ($CEA_1 = 300$, dive angles (θ) between 40 degrees and 60 degrees with tracking times of about 5 seconds; $t_r = 5$).

The BDU-33 practice bomb, dropped from a multiple ejector rack (MER) is used for this training. True airspeeds on the order of 500 knots and release altitudes on the order of 8000 feet AGL are employed in the delivery maneuver. From Figures 6 and 8, the wind bombing error factor (E) is approximately 28 feet/knot (after interpolating between $\theta = 40$ degrees, $\theta = 60$ degrees, TAS = 400 knots, TAS = 600 knots). The present method of providing winds-aloft data (or more precisely, the method used when the data used to compute CEA_1, was collected) equates to a time lag of (from Equation 10)

$$\bar{t} = \tfrac{1}{2}\ \text{hour} + 2/2\ \text{hours} = 1\tfrac{1}{2}\ \text{hours}$$

From Table 1, $\sigma = 13$ knots

Then for $\bar{t} = 1\frac{1}{2}$ hours (from Equation 11)

$$\sigma_t = 0.2\ \sigma t^{\frac{1}{2}} = 0.2(13)\ (3/2)^{\frac{1}{2}}$$

$$\sigma_t = 3.18\ \text{knots}$$

The variability due to distance, $d = \frac{1}{2}$ mile, is (from Equation 7)

$$\sigma_d = 1.3\ d^{\frac{1}{2}} = 1.3(\tfrac{1}{2})^{\frac{1}{2}}$$

$$\sigma_d = 0.92\ \text{knots}$$

The total RMSE for wind variability is then (from Equation 9)

$$\sigma_{T1} = +(\sigma_t{}^2 + \sigma_d{}^2 + \sigma_e{}^2)^{\frac{1}{2}}$$

$$\sigma_{T1} = +(3.18^2 + 0.92^2 + 2.5^2)^{\frac{1}{2}}$$

$$\sigma_{T1} = 4.14 \text{ knots}$$

Consider two alternative support methods: (1) changing pilot balloon observation frequency to every 4 hours; and (2) deleting on-site pilot balloon support and substituting numerical model forecast winds aloft.

(1) Alternative 1: Changing t_f to 4 hours results in

$$\bar{t} = 2\tfrac{1}{2} \text{ hours}$$

$$\sigma_t = 0.2\ \sigma t^{\frac{1}{2}} = 0.2(13)\ (5/2)^{\frac{1}{2}} = 4.11 \text{ knots}$$

Then

$$\sigma_{T2} = +(4.11^2 + 0.92^2 + 2.5^2)^{\frac{1}{2}}$$

$$\sigma_{T2} = 4.89 \text{ knots}$$

$$\Delta(\sigma^2) = (4.89^2 - 4.14^2)$$

$$\Delta(\sigma^2) = 6.77 \text{ knots}^2$$

From Figure 3 (for CEA_1 = 300 feet), ΔCEA = 8 feet.

(2) Alternative 2: For the Cuddeback Lake range, assume that the daily training period is from 1400Z to 0200Z. Sorties scheduled to enter the range prior to 1600Z must use forecast wind based on the previous 0000Z observed upper-air data. The so-called first period is of 2 hours duration with a mid-point forecast valid time of 15 hours; the second period is of 10 hours duration with a mid-point valid time of 9 hours (i.e., 9 hours after 1200Z). From Figure 15, values of σ_{e1} and σ_{e2} are 7.95 knots and 7.35 knots, respectively. This corresponds to a weighted σ_e of (from Equation 12)

$$\sigma_e = 2/12\ (7.95) = 10/12\ (7.35)$$

$$\sigma_e = 7.45 \text{ knots}$$

The value of σ_t is found from

$$\sigma_t = 0.1\sigma = 0.1(13)$$

$$\sigma_t = 1.3 \text{ knots}$$

The value of $\sigma_d = 0$ since forecast winds can be tailored to the location of the target. Then

$$\sigma_{T2} = +(1.3^2 + 0^2 + 7.45^2)^{\frac{1}{2}}$$

$$\sigma_{T2} = 7.56 \text{ knots}$$

$$\Delta(\sigma^2) = (7.56^2 - 4.14^2)$$

$$\Delta(\sigma^2) = 40.1 \text{ knots}^2$$

From Figure 3, ΔCEA = 40 feet.

Consequently, considering the statistical effect (mean bombing accuracy) the CEA would be expected to increase from 300 feet to 308 feet (2.7 percent increase) if 4-hourly pibal support were used. The CEA would be expected to increase from 300 feet to 340 feet (13.3 percent increase) if forecast winds were to be used; all other factors remaining equal.

b. Example 2. Consider the Dare County range controlled by the 4th TFW at Seymour-Johnson AFB. Pibal observations are taken at this range every 2 hours when training is conducted. The pibal site is close enough to the target-scoring complex to be considered as being at the target site (d = 0). During the period when this pibal support was provided to aircrews, assume that the CEA for the 4th TFW is 80 feet for LAB deliveries using the MK-106 practice bomb. These deliveries have employed AGL altitudes between 500 feet and 1000 feet, and true airspeeds of around 500 knots. From Figure 14, E = 12 feet/knot. As with the Cuddeback Lake example, $\bar{t} = 1\frac{1}{2}$ hours. From Table 1, σ = 18 knots. Then for $\bar{t} = 1\frac{1}{2}$ hours

$$\sigma_t = 0.2\ \sigma t^{\frac{1}{2}} = 0.2(18)\ (3/2)^{\frac{1}{2}}$$

$$\sigma_t = 4.41 \text{ knots}$$

Then

$$\sigma_{T1} = +(4.41^2 + 0^2 + 2.5^2)^{\frac{1}{2}}$$

$$\sigma_{T1} = 5.01 \text{ knots}$$

It is desired to estimate the expected degradation in accuracy of LAB deliveries using high-drag bombs (similar to the MK-106) if the 4th TFW deployed to the European theater where (under the scenario of a hostile environment) forecast winds over the target area are provided to aircrews for mission planning. For daylight manual deliveries, the flying period is from 0700Z to 1900Z (on an average annual basis). The first period is from 0700Z to 1600Z (9 hours) and the second period from 1600Z to 1900Z (3 hours). The values of σ_{e1} and σ_{e2} are (from Figure 15) 7.35 knots (for a $11\frac{1}{2}$-hour mid-point valid time) and 6.75 knots (for a $5\frac{1}{2}$-hour mid-point valid time). Then

$$\sigma_e = 9/12\ (7.35) + 3/12\ (6.75)$$

$$\sigma_e = 7.2 \text{ knots}$$

and

$$\sigma_d = 0 \text{ (for tailored support)}$$

For σ_t

$$\sigma_t = 0.1\sigma \ (\sigma = 20 \text{ knots from 3 WWM 105-5 [9]})$$

$$\sigma_t = 2 \text{ knots}$$

Then

$$\sigma_{T2} = +(2^2 + 0^2 + 7.2^2)^{\frac{1}{2}}$$

$$\sigma_{T2} = 7.47 \text{ knots}$$

$$\Delta(\sigma^2) = (7.47^2 - 5.01^2)$$

$$\Delta(\sigma^2) = 30.8 \text{ knots}^2$$

From Equation (3) for CEA_2

$$CEA_2 = +[80^2 + 12^2/1.27\ (30.8)]^{\frac{1}{2}}$$

$$CEA_2 = 99 \text{ feet}$$

$$\Delta CEA = (99 - 80) = 19 \text{ feet}$$

Therefore, the bombing accuracy for this delivery maneuver is expected to increase 23.7 percent to a CEA of 99 feet for the European scenario described.

6. Analysis Limitations and Possible Bias

a. A key assumption for this analysis is that wind error-induced bombing errors are independent of those errors due to other causes. It is logical to expect that, if wind errors become large, then the aircrew's delivery techniques would be impaired in attempting to correct for unanticipated winds aloft. In these circumstances, the equation for determining the change in CEA would be an underestimate of the change that is likely to occur. However, the assumption involved in determining the wind bombing error factor (E) is that the pilot takes no corrective action for wind errors on delivery. That is, of course, not strictly valid since aircrews do attempt corrections for wind errors that are recognized in flight. This makes the values of E overestimates of the actual effect of wind errors on bomb errors. The net effect is that the above factors are compensating, but the degree to which this is true is not known. In the analysis presented in this report, these factors are treated as being exactly compensating.

b. When applying this analysis it should be remembered that only statistical, or mean effects are considered. On any given day a pilot-balloon wind or forecast wind may be exactly the same as the actual wind. On the other extreme, the observed wind could be from 180 degrees at 20 knots with the actual wind a short time later (or distance away) being from 360 degrees at 20 knots (as with the passage of a cold front) giving a 40-knot absolute error. However, the probability of this occurring is low when compared to the type of wind conditions experienced on a daily basis. The root mean square error (RMSE) or wind variability statistics can be viewed for individual sorties as the likelihood or probability of a wind error greater than a certain value occurring. Assuming that these wind errors follow a circular normal distribution, then the probability that an absolute value vector wind error is greater than the RMSE (or computed values of σ_T) is 36.8 percent. If the RMSE (or σ_T) is multiplied by the wind bombing error factor (E) then the resulting value is

the distance beyond which bombing errors will be found with a probability of 36.8 percent. The probabilities for other values of wind errors (relative to the RMSE (or σ_T)) is given by

$$\text{Probability [wind error > y(RMSE)]} = e^{-y^2} \quad (13)$$

c. A possible alternative not discussed in the text of this analysis is to make pibal support a function of the expected synoptic weather situation on the gunnery range. While it may be difficult to implement from operational and manpower considerations, it is logical to increase the accuracy (i.e., frequency) of pibal winds-aloft observations if the forecast synoptic situation is such as to make ballistic winds highly variable in time and space. For those cases when weather features are less variable, the frequency of pibals could be reduced or not taken at all, and forecast winds substituted for them.

d. The 850-mb level wind (approximately 5000-feet AGL) was taken to be representative of the ballistic wind in this analysis. For munitions released above this altitude, this approximation is not likely to cause any significant error. However, for munitions delivered at lower levels (e.g., LAB), the 850-mb wind variability may underestimate the true variability experienced at lower altitudes, especially for winds within the atmospheric boundary layer (surface to around 2500-feet AGL).

e. When considering forecast winds as a support alternative, the RMSE statistics presented are slightly overestimated. This is based on the assumption that such winds can be locally modified as necessary for forecasting personnel.

7. Analysis Procedure Outline

The following is a summary of the general procedures that should be followed in order to apply this analysis:

a. For a specific weapon and delivery maneuver (or maneuver envelope; dive angles, airspeeds, etc.), determine CEA based on locally available Weapons Delivery Qualifications Records, AF Form 107 (reference paragraph 6, AFR 55-89 [5]).

b. Determine the wind bombing error factor (E) for the selected delivery maneuver (or for the "mean" maneuver if a maneuver envelope is selected).

c. Compute the total wind RMSE (σ_{T1}) for the wind data provided to aircrews during the period when the bombing error data used to compute CEA_1 were generated.

d. Compute the total wind RMSE (σ_{T2}) for the wind data provided to aircrews under a hypothetical alternative method of providing these data. From σ_{T1}^2 and σ_{T2}^2, compute $\Delta(\sigma^2) = \sigma_{T2}^2 - \sigma_{T1}^2$.

e. From the appropriate nomograms (or the original equation), determine the expected CEA for the alternative method of providing wind data based on the above values for CEA_1, E, and $\Delta(\sigma^2)$.

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[6] US Air Force: "Ground Attack Phase Manual," USAF Operational Training Course F-4, Tactical Air Command/DOXS, November 1974.

[7] US Air Force: "Aircrew Weapons Delivery Manual (Non-Nuclear)," T.O. 1F-4C-34-1-1, February 1976.

[8] US Air Force: "Aircrew Weapons Delivery Tables (Non-Nuclear)," T.O. 1F-4C-34-1-2, October 1974.

[9] US Air Force: "Climatological Wind Factor Calculator: Vector Standard Deviation Charts," 3 WWM 105-5, 3rd Weather Wing, 12 February 1962.

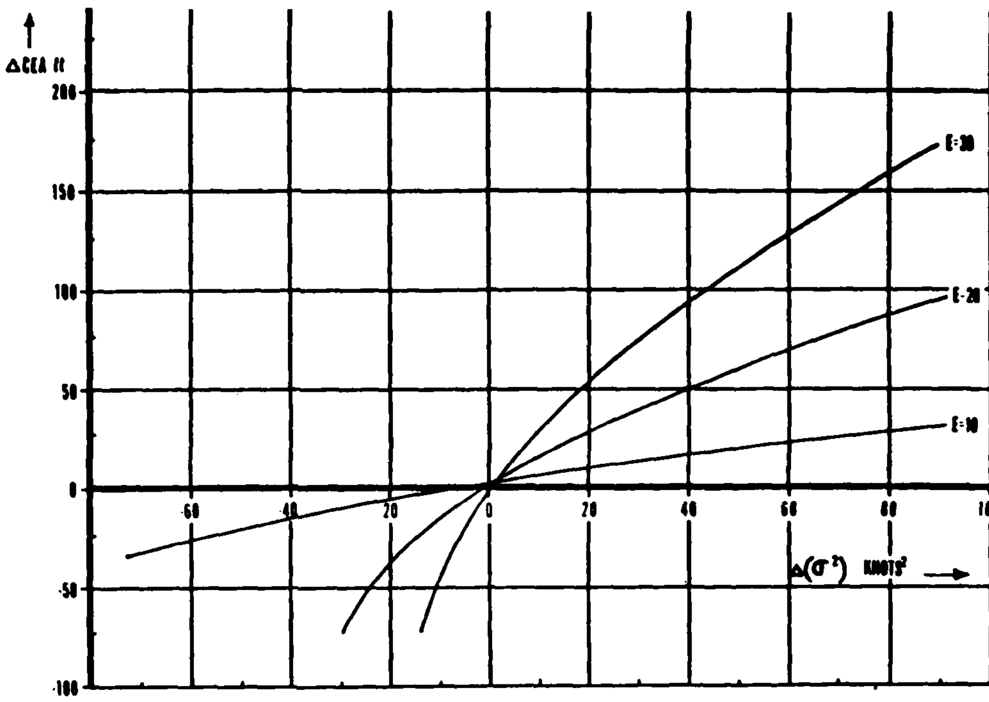


Figure 1. ΔCEA as a Function of E and $\Delta(\sigma^2)$ for CEA_1 = 100 Feet.

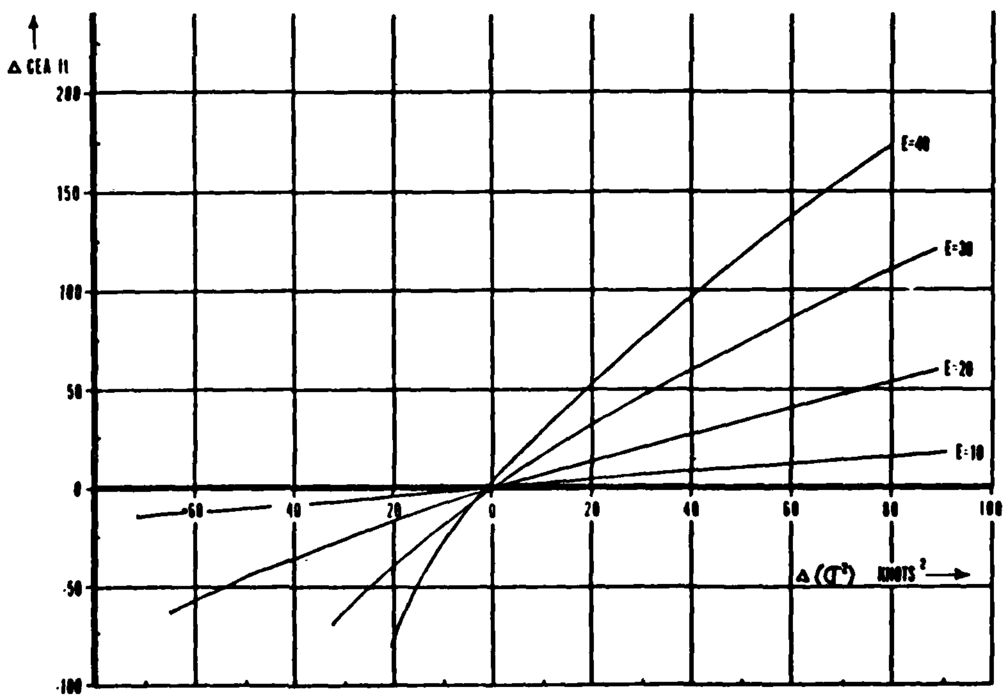


Figure 2. ΔCEA as a Function of E and $\Delta(\sigma^2)$ for CEA_1 = 200 Feet.

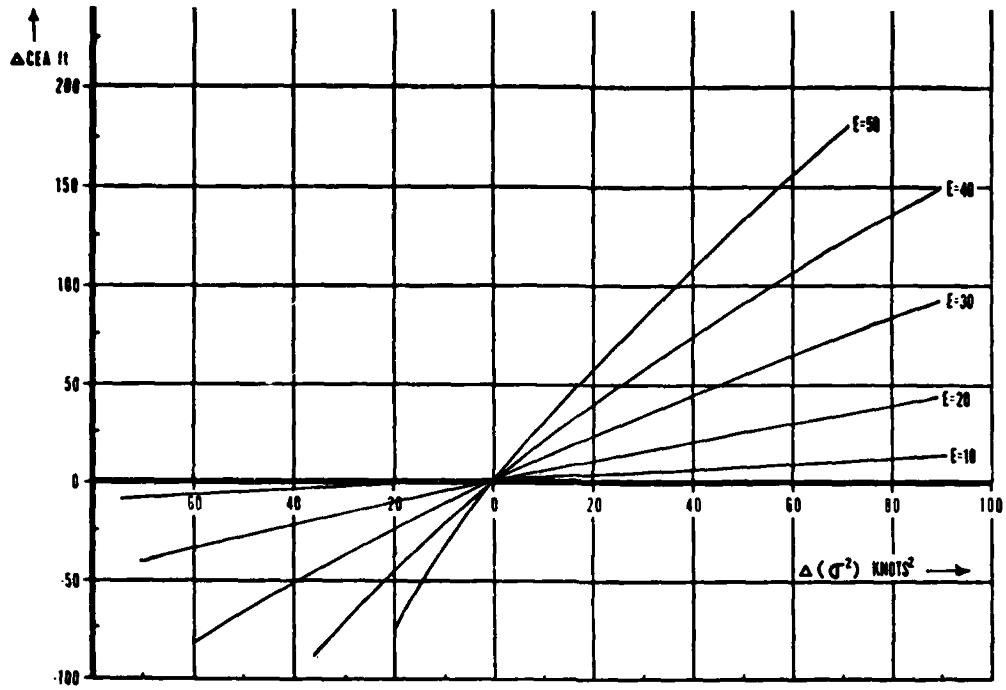


Figure 3. ΔCEA as a Function of E and $\Delta(\sigma^2)$ for CEA_1 = 300 Feet.

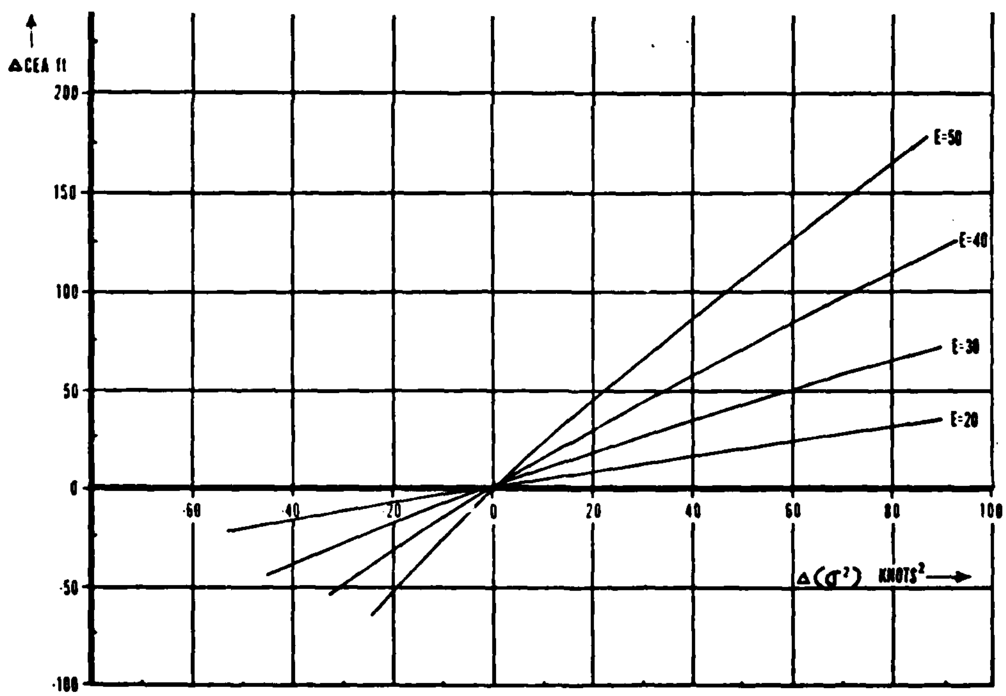


Figure 4. ΔCEA as a Function of E and $\Delta(\sigma^2)$ for CEA_1 = 400 Feet.

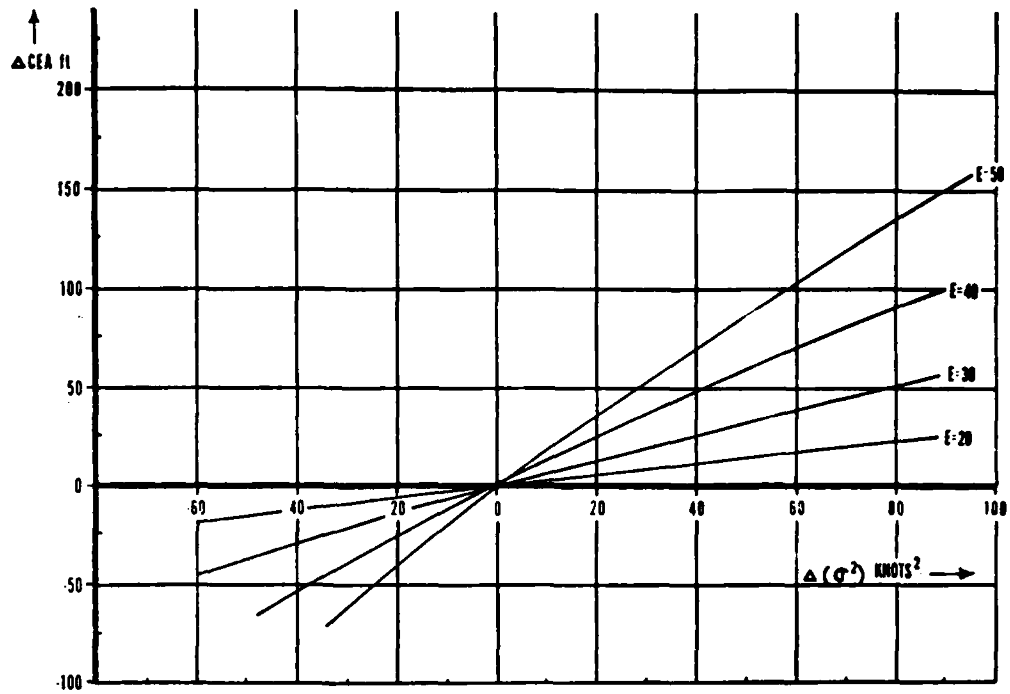


Figure 5. ΔCEA as a Function of E and $\Delta(\sigma^2)$ for CEA_1 = 500 Feet.

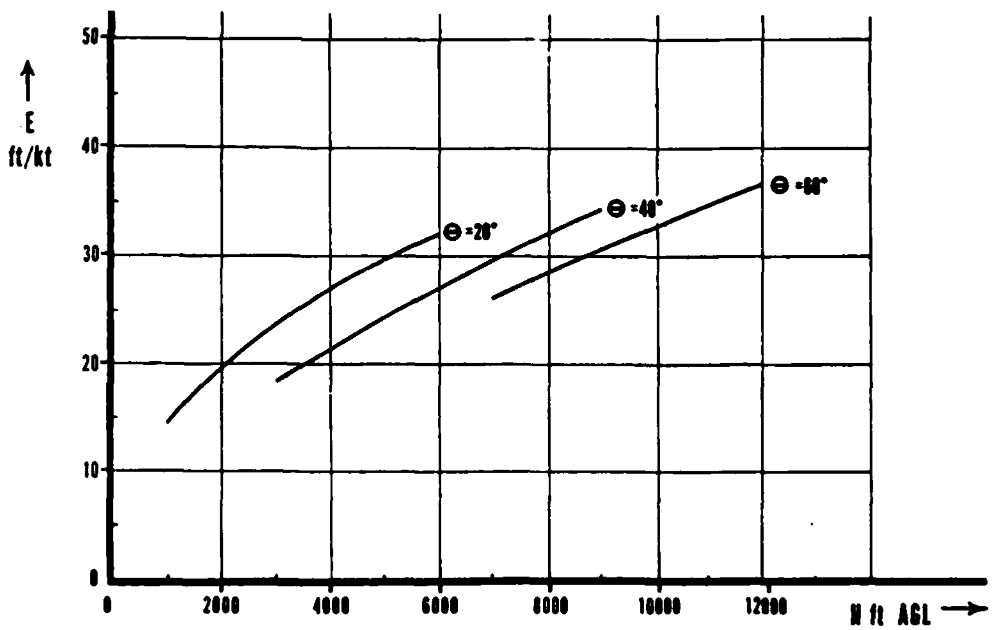


Figure 6. Wind Bombing Error Factor (E): MER/TER Release, BDU-33, tr = 5 sec, TAS = 400 kt.

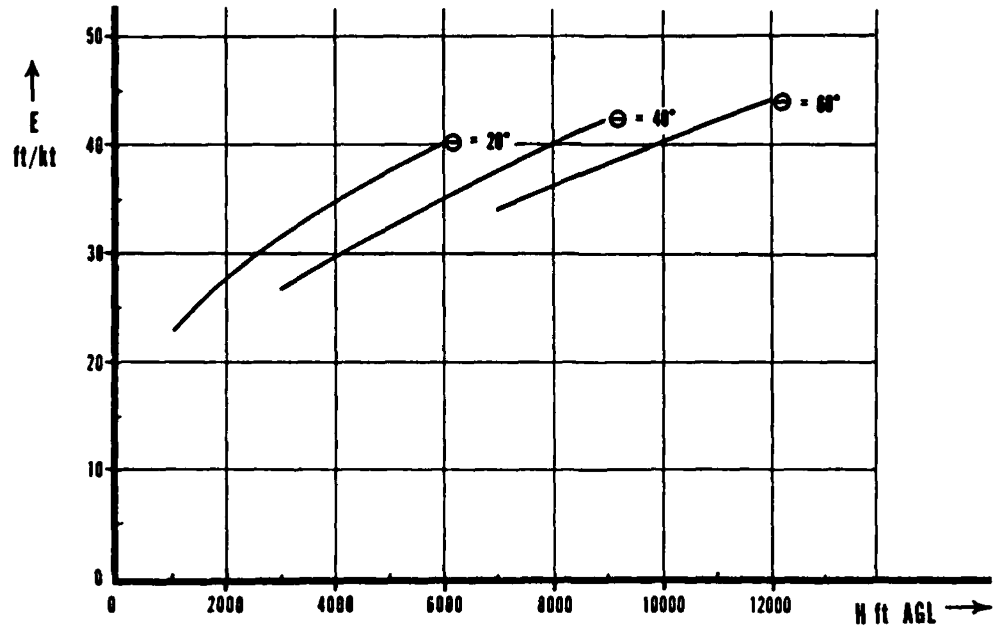


Figure 7. Wind Bombing Error Factor (E): MER/TER Release, BDU-33, tr = 10 sec, TAS = 400 kt.

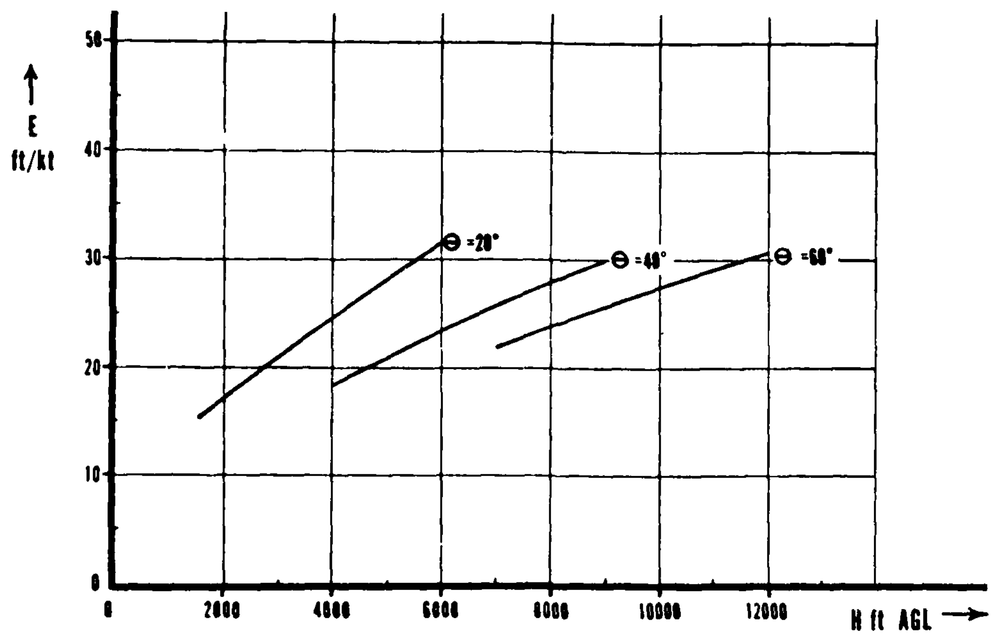


Figure 8. Wind Bombing Error Factor (E): MER/TER Release, BDU-33, tr = 5 sec, TAS = 600 kt.

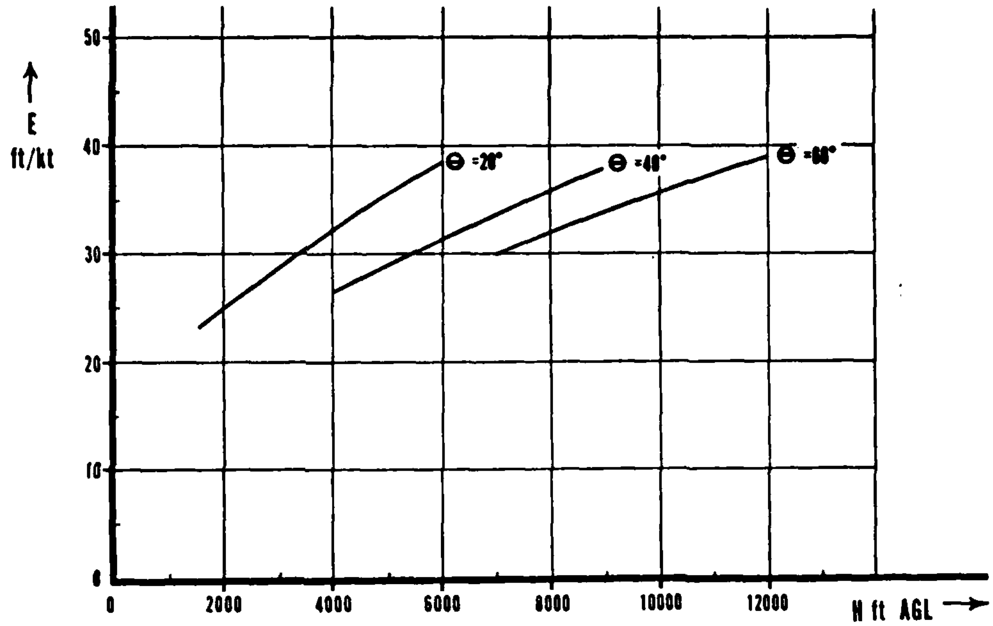


Figure 9. Wind Bombing Error Factor (E): MER/TER Release, BDU-33, tr = 10 sec, TAS = 600 kt.

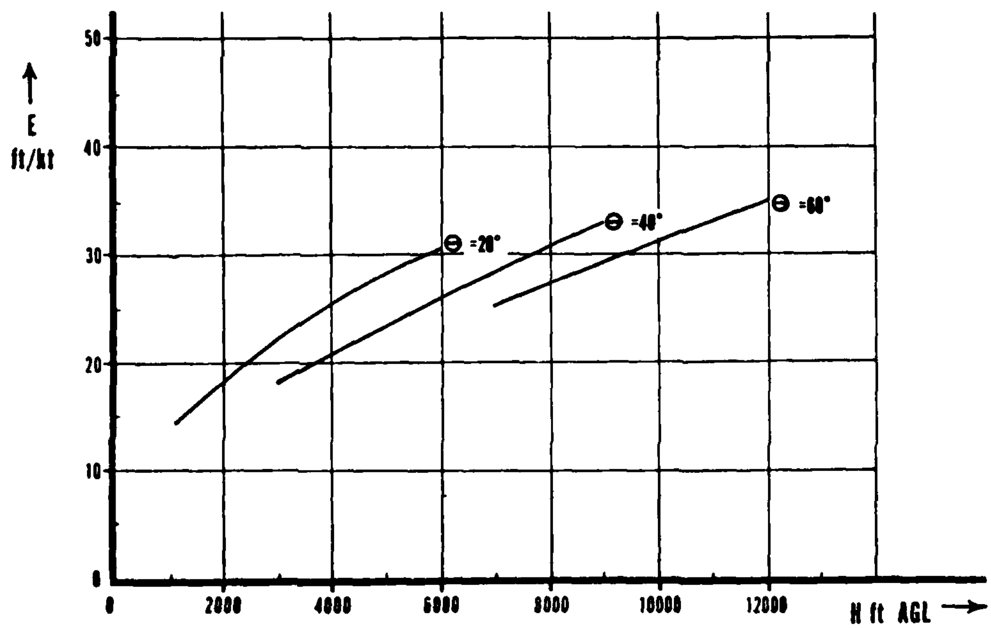


Figure 10. Wind Bombing Error Factor (E): SUU-20 Release, BDU-33, tr = 5 sec, TAS = 400 kt.

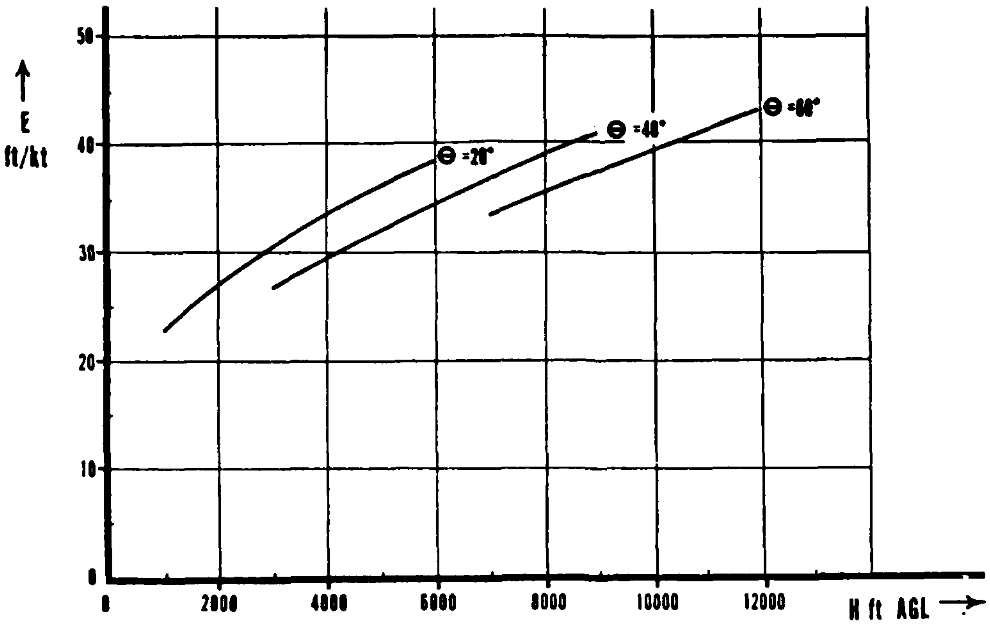


Figure 11. Wind Bombing Error Factor (E): SUU-20 Release, BDU-33, tr = 10 sec, TAS = 400 kt.

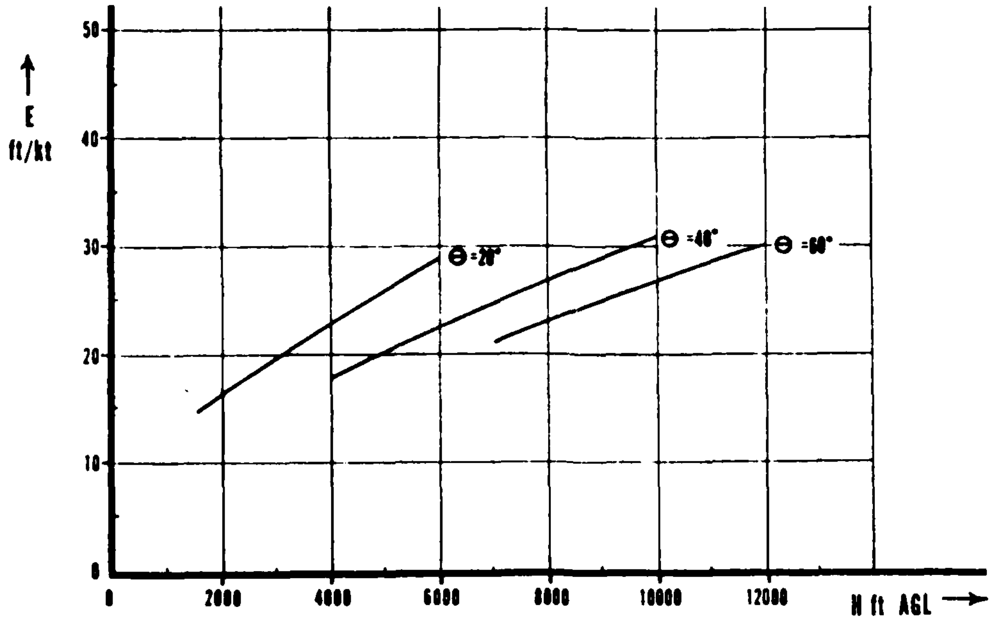


Figure 12. Wind Bombing Error Factor (E): SUU-20 Release, BDU-33, tr = 5 sec, TAS = 600 kt.

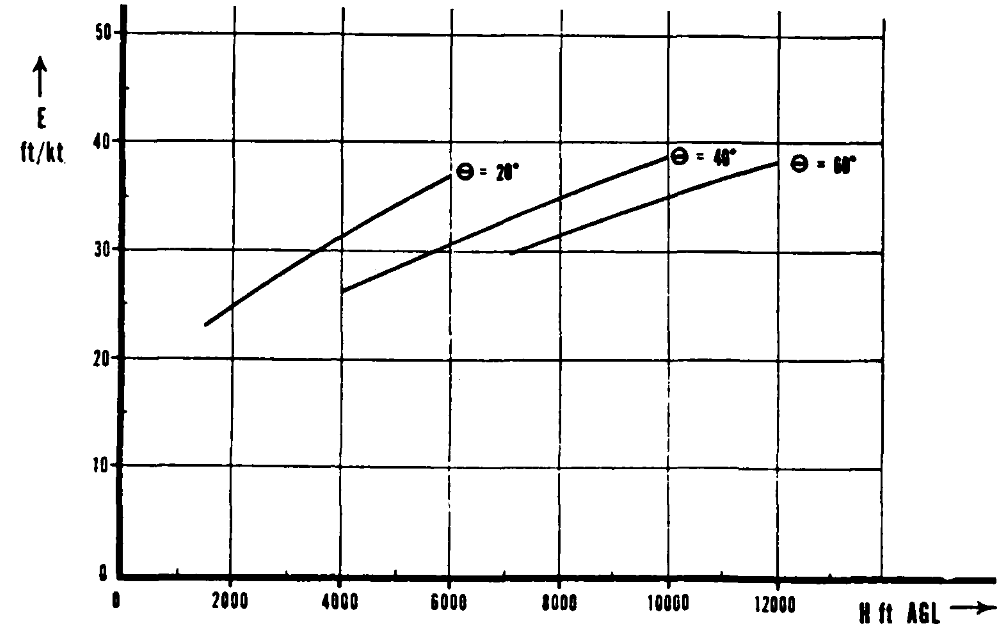


Figure 13. Wind Bombing Error Factor (E): SUU-20 Release, BDU-33, tr = 10 sec, TAS = 600 kt.

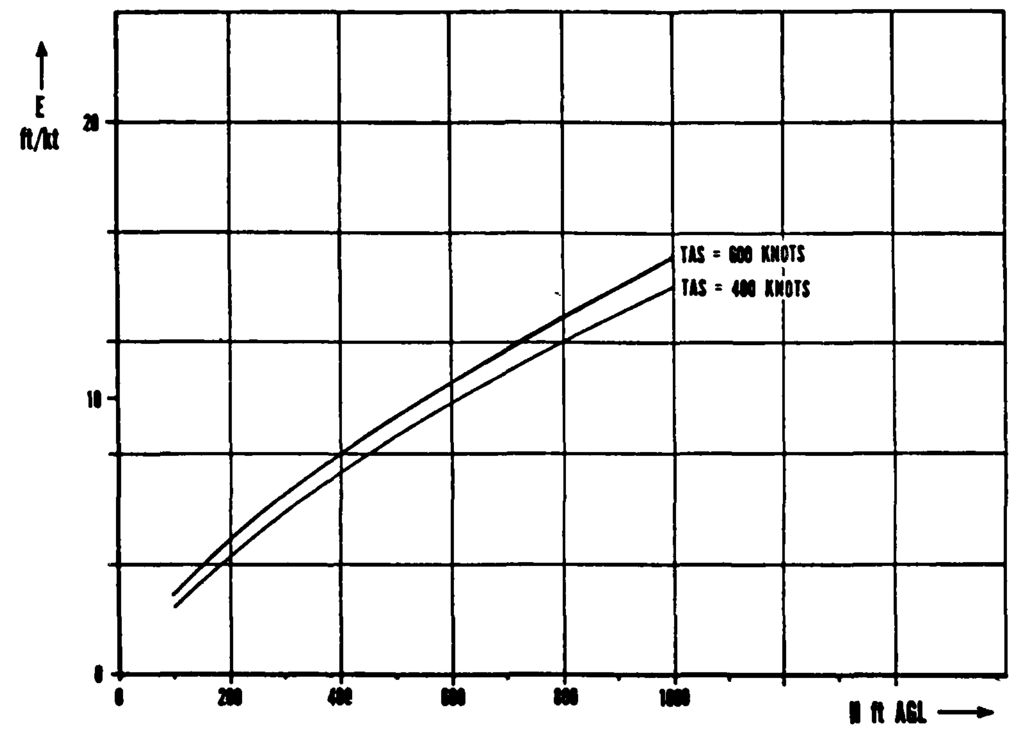


Figure 14. Wind Bombing Error Factor (E): SUU-20 Release, MK-106, Dive Angle = 0, TAS = 400 kt, TAS = 600 kt.

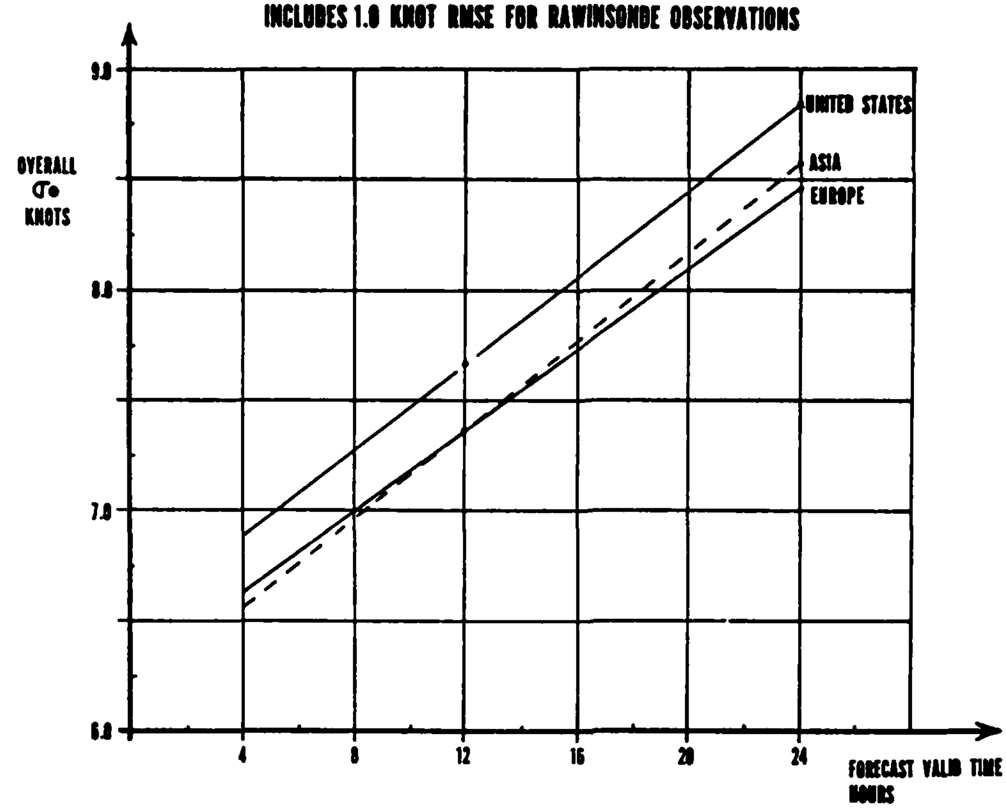


Figure 15. AFGWC ½-Mesh Boundary Layer Model RMSE Annual Forecast Wind Statistics for the 1600-Meter AGL Level: United States, Europe, and Asia.

Appendix A

EXPECTED CEA DUE TO A CHANGE IN WIND INFORMATION ERROR VARIANCE

<u>Definitions</u>:

ρ = bomb error due to an error between forecast winds aloft and actual winds aloft

r = bomb error due to <u>other</u> causes than wind errors

CE = resultant circular error

θ = angle between ρ and r

$f(\theta)$ = probability density function of θ

$g(\rho)$ = probability density function of ρ

$h(r)$ = probability density function of r

ΔV = absolute value of the vector difference between forecast winds aloft and actual winds aloft

E = wind error factor; feet of bomb error per knot of wind error (absolute value of the vector difference error)

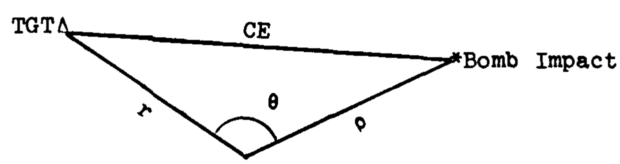
$U_j(X)$ = jth moment of the random variable X

<u>Assumption</u>: ρ, r, and θ are <u>independent</u>. That is, the distribution of non-wind related bomb errors, r, does not change with a change in wind error-induced bomb errors, ρ.

<u>Discussion</u>: CE is related to ρ, r, and θ by

$$CE = +(\rho^2 + r^2 - 2\rho\, r \cos\theta)^{\frac{1}{2}} \tag{A-1}$$

where the geometry is



Since the random variables ρ, r, and θ are independent, then

$$U_2(CE) = \int_0^{\infty}\int_0^{\infty}\int_0^{2\pi} (\rho^2 + r^2 + 2\rho\, r \cos\theta)\, f(\theta)\, g(\rho)\, h(r)\, d\theta\, d\rho\, dr \tag{A-2}$$

<u>Assumption</u>: The distribution of θ is uniform over the interval $(0, 2\pi)$ i.e., $f(\theta) = 1/2\pi$

Therefore

$$U_2(CE) = U_2(\rho) + U_2(r) \tag{A-3}$$

If $g(\rho)$ is changed, due to providing winds-aloft information by an alternate method, then

$$U_2'(CE) = U_2'(\rho) + U_2'(r) \tag{A-4}$$

where the primes (′) refer to the alternate method of providing winds-aloft information. Since ρ and r are assumed to be independent, the second moment of r does not change, i.e.,

$$U_2(r) = U_2'(r) \tag{A-5}$$

Subtracting Equation (A-3) from Equation (A-4)

$$U_2'(CE) - U_2(CE) = U_2'(\rho) - U_2(\rho) \tag{A-6}$$

<u>Assumption</u>: Bomb errors, CE, are distributed according to a circular normal distribution, i.e.,

$$G(CE) = \frac{CE}{\beta^2} \exp\left(-\frac{CE^2}{2\beta^2}\right) \tag{A-7}$$

For any given distribution, the relation between the second moment and the square of the first moment will be constant, i.e.,

$$U_2'(CE) = k' U_1'^2(CE)$$

$$U_2(CE) = k\, U_1^2\,(CE) \tag{A-8}$$

For a circular normal distribution given by Equation (A-7)

$$U_j(CE) = \beta^j\, 2^{\frac{1}{2}j}\, \Gamma\left[\tfrac{1}{2}\,(2 + j)\right] \tag{A-9}$$

where $\Gamma(\ )$ is the gama function.

Therefore

$$U_1(CE) = \frac{\sqrt{2\pi}}{2}\,\beta \tag{A-10}$$

and

$$U_2(CE) = 2\beta^2 \tag{A-11}$$

Consequently

$$k = k' = \frac{4}{\pi} = 1.273 \tag{A-12}$$

Substituting into Equation (A-6)

$$k\left[U_1'^2(CE) - U_1^2(CE)\right] = U_2'(\rho) - U_2(\rho)$$

$$U_1'(CE) = +\left\{U_1^2(CE) + \frac{1}{k}\left[U_2'(\rho) - U_2(\rho)\right]\right\}^{\frac{1}{2}} \quad \text{(A-13)}$$

The first moments $U_1(CE)$ and $U_1'(CE)$ are estimated by the circular error averages (CEA) under both methods of support. Let $U_1(CE) \simeq CEA_1$ and $U_1'(CE) \simeq CEA_2$ where

$$CEA = \frac{1}{N}\sum_{i=1}^{N} CE_i \quad \text{(A-14)}$$

N = Total number of record deliveries

From the definitions above

$$\rho = E(\Delta V)$$

$$U_2(\rho) = U_2(E\Delta V) = E^2 U_2(\Delta V)$$

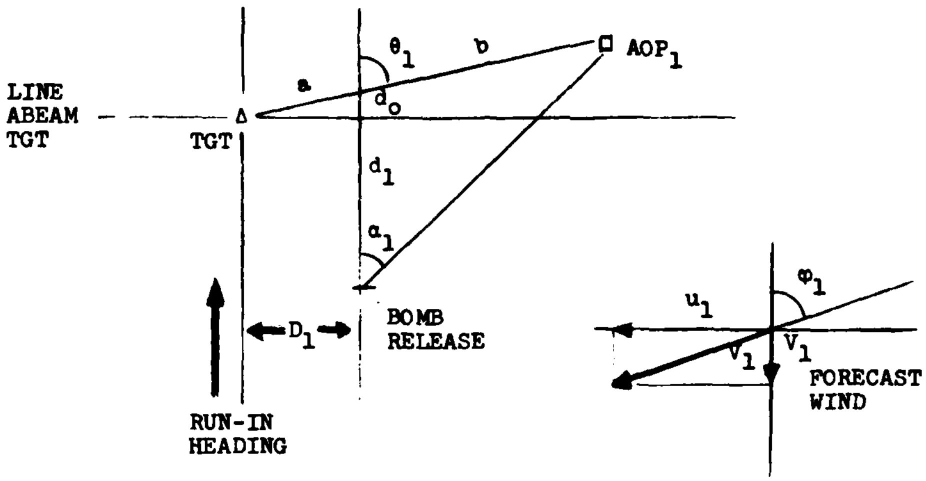
where $U_2(\Delta V)$ is the variance of wind errors or wind error variance. In practice, $[U_2(\Delta V)]^{\frac{1}{2}}$ is estimated by the root mean square error (RMSE) of measured wind errors. Let σ represent this RMSE, and $U_2(\Delta V) \simeq \sigma_1^2$ and $U_2'(\Delta V) \simeq \sigma_2^2$, and let $\Delta(\sigma^2) = \sigma_1^2 - \sigma_1^2$. Therefore

$$CEA_2 = +\left[CEA_1 + \frac{E^2}{k}\Delta(\sigma^2)\right]^{\frac{1}{2}} \quad \text{(A-15)}$$

Appendix B

WIND BOMBING ERROR FACTOR (E) FOR LOW ANGLE BOMB (LAB) LEVEL CRABBING DELIVERY (Dive Angle = 0°)

Reference: T.O. 1F-4C-34-1-1. Section IV, Error Analysis [7]



Forecast Wind, from φ_1 degrees at V_1 knots

$$v_1 = V_1 \cos \varphi_1 \text{ range wind}$$
$$u_1 = V_1 \sin \varphi_1 \text{ cross wind} \qquad \text{(B-1)}$$

<u>Definitions</u>:

- t_c = bomb time of fall (seconds)
- V_A = aircraft true airspeed (knots)
- R_3 = bomb range (feet)
- D_1 = upwind track offset distance (feet) due to forecast winds
- α_1 = crab angle
- d' = distance along aircraft heading to a point abeam the target (relative to the run-in heading) at bomb release.

<u>Assumption</u>: A sight-depression (in miles) is used to determine release distance.

$$D_1 = u_1 \left(1.69\ t_c - \frac{R_3}{V_A}\right) \qquad \text{(B-2)}$$

AOD_1 = aim-off distance (combat offset)

$$AOD_1 = 1.69\ t_c\ V_1 \qquad \text{(B-3)}$$

then

$$a = \frac{D_1}{\sin \varphi_1} \tag{B-4}$$

$$b = AOD_1 - a = 1.69\ t_c\ V_1 - \frac{V_1 \sin \varphi_1 \left(1.69\ t_c - \frac{R_2}{V_A}\right)}{\sin \varphi_1}$$

$$b = \frac{V_1\ R_3}{V_A} \tag{B-5}$$

$$d_o = \frac{D_1}{\tan \varphi_1} = \frac{\cos \varphi_1}{\sin \varphi_1}\left[V_1 \sin \varphi_1 \left(1.69\ t_c - \frac{R_3}{V_A}\right)\right]$$

$$d_o = V_1 \cos \varphi_1 \left(1.69\ t_c - \frac{R_3}{V_A}\right) = v_1 \left(1.69\ t_c - \frac{R_3}{V_A}\right) \tag{B-6}$$

From the Law of Sines

$$\frac{\frac{V_1\ R_3}{V_A}}{\sin \alpha_1} = \frac{d_1 + d_o}{\sin (\varphi_1 - \alpha_1)} \tag{B-7}$$

$$d_1 + d_o = \left(\frac{V_1\ R_3}{V_A}\right) \frac{\sin (\varphi_1 - \alpha_1)}{\sin \alpha_1} = \frac{V_1\ R_3}{V_A}\ \frac{(\sin \varphi_1 \cos \alpha_1 - \cos \varphi_1 \sin \alpha_1)}{\sin \alpha_1}$$

Since $V_A \sin \sigma_1 = V_1 \sin \varphi_1$, in order to maintain run-in heading of the planned ground track,

$$\sin \alpha_1 = \frac{V_1}{V_A} \sin \varphi_1$$

Then

$$d_o + d_1 = R_3 \left(\cos \alpha_1 - \frac{\cos \varphi_1}{\sin \varphi_1} \sin \alpha_1\right)$$

$$d_o + d_1 = R_3 \left[\cos \sigma_1 - \frac{\cos \varphi_1 \left(\frac{V_1}{V_A}\right) \sin \varphi_1}{\sin \varphi_1}\right]$$

$$d_o + d_1 = R_3 \left(\cos \sigma_1 - \frac{V_1}{V_A} \cos \varphi_1\right) \tag{B-8}$$

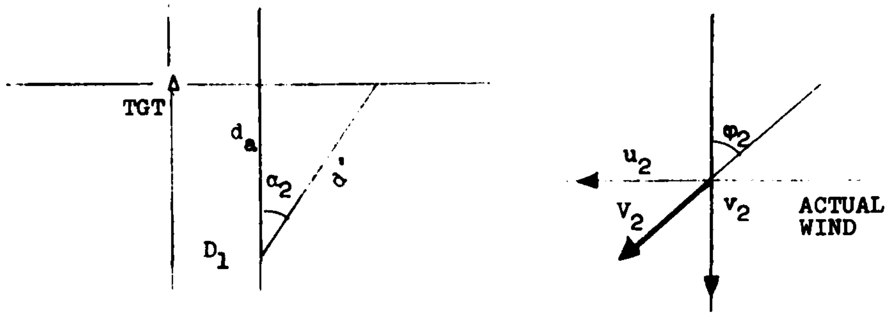
$$d_1 = R_3 \left(\cos \alpha_1 - \frac{V_1}{V_A} \cos \varphi_1\right) - V_1 \cos \varphi_1 \left(1.69\ t_c - \frac{R_3}{V_A}\right)$$

$$d_1 = R_3 \cos \alpha_1 - 1.69\ t_c\ V_1 \cos \varphi_1 \tag{B-9}$$

$$d' = \frac{d_1}{\cos\alpha_1} = \frac{R_3\cos\alpha_1 - 1.69\, t_c V_1 \cos\varphi_1}{\cos\alpha_1}$$

$$d' = R_3 - 1.69\, t_c V_1 \frac{\cos\varphi_1}{\cos\alpha_1} \qquad \text{(B-10)}$$

__Assumption__: With "actual" winds from φ_2 degrees at V_2 knots the pilot applies enough crab (α_2) to maintain run-in heading. The ground track, offset by D_1, is flown with crab angle α_2. When the sight crosses a line abeam the target (relative to the run-in heading) the pilot releases the bomb.



d_a = actual release distance along the ground track

$d_a = d' \cos\alpha_1$

$$d_a = R_3\cos\alpha_1 - 1.69\, t_c V_1 \cos\varphi_1 \left(\frac{\cos\alpha_2}{\cos\alpha_1}\right) \qquad \text{(B-11)}$$

d_2 = "required" release distance along the ground track for an actual wind from φ_2 deg ees at V_2 knots

$$d_2 = R_3\cos\alpha_2 - 1.69\, t_c V_1 \cos\varphi_2 \qquad \text{(B-12)}$$

ΔR = error along run-in heading (range-wind error)

$\Delta R = d_2 - d_a$

$$\Delta R = R_3\cos\sigma_2 - 1.69\, t_c V_2\cos\varphi_2 - R_3\cos\alpha_2 + 1.69\, t_c V_1\cos\varphi_1 \left(\frac{\cos\alpha_2}{\cos\alpha_1}\right)$$

$$\Delta R = 1.69\, t_c \left[V_1\cos\varphi_1 \left(\frac{\cos\alpha_2}{\cos\alpha_1}\right) - V_2\cos\alpha_2\right]$$

$$\Delta R = 1.69\, t_c \left[v_1 \left(\frac{\cos\sigma_2}{\cos\alpha_1}\right) - v_2\right] \qquad \text{(B-13)}$$

ΔP = error across run-in heading (cross-wind error)

D_2 = "required" upwind offset distance for an actual wind from φ_2 degrees at V_2 knots

$$D_2 = U_2 \left(1.69\ t_c - \frac{R_3}{V_A}\right) \tag{B-14}$$

$$\Delta P = D_2 - D_1$$

$$\Delta P = \left(1.69\ t_c - \frac{R_3}{V_A}\right)(u_2 - u_1)$$

Let

$$\Delta v = u_2 - u_1 = \text{cross-wind error}$$

$$\Delta v = v_2 - v_1 = \text{range-wind error}$$

Then

$$\Delta P = \left(1.69\ t_c - \frac{R_3}{V_A}\right)\Delta u \tag{B-15}$$

For <u>normal</u> true airspeeds and wind speeds involved, assume

$$\alpha_1 \simeq 0°,\ \cos\alpha_1 \simeq 1.0$$

$$\alpha_2 \simeq 0°,\ \cos\alpha_2 \simeq 1.0$$

Therefore

$$\frac{\cos\alpha_2}{\cos\alpha_1} \simeq 1.0$$

$$\Delta R = 1.69\ t_c\ (v_1 - v_2) \tag{B-16}$$

$$e = \text{total bomb error}$$

$$e^2 = \Delta R^2 + \Delta P^2$$

$$e^2 = \left(1.69\ t_c - \frac{R_3}{V_A}\right)^2 \Delta u^2 + \left(1.69\ t_c\right)^2 \Delta v^2$$

$$e^2 = (1.69\ t_c)^2\ (\Delta u^2 + \Delta v^2) - \left[\frac{2(1.69)t_c\ R_3}{V_A} - \frac{R_3^2}{V_A^2}\right]\Delta u^2 \tag{B-17}$$

Let

$$\Delta V^2 = \Delta u^2 + \Delta v^2$$

where ΔV is the absolute value of the vector difference between the forecast wind and the actual wind. For a given ΔV^2, e^2 is a maximum when $\Delta u^2 = 0$ and a minimum when $\Delta u^2 = \Delta V^2$. This is so, since

$$\left[\frac{2(1.69)t_c\ R_3}{V_A} - \frac{R_3^2}{V_A^2}\right]$$

is always positive. Taking a median error, $\Delta u^2 = \Delta v^2 = \frac{\Delta V^2}{2}$, converting this expression to yield a "feet per knot" error (E),

$$E = +\left(2.86\ t_c^2 - \frac{1.69\ R_3\ t_c}{V_A}\ \frac{R_3^2}{2V_A^2}\right)^{\frac{1}{2}} \tag{B-18}$$

For dive angles > 0°, substitute $V_A \cos\theta$ for V_A. However, for $\theta = 10°$ this effect is small and will be ignored.

GLOSSARY

AFGWC	Air Force Global Weather Central
AGL	above ground level
AOD	aim-off distance
BDU-33	low-drag practice bomb
CE	circular error
CEA	circular error average
CEP	circular error probable
DB	dive bombing
E	wind bombing error factor
HADB	high altitude dive bombing
LAB	low angle bombing
MC	mission capable
MER	multiple ejector rack
MER/TER	multiple ejector rack/triple ejector rack
MK-106	high-drag practice bomb
MR	mission ready
MSL	mean sea level
RMSE	root mean square error
SUU-20	disperser pod
TAC	Tactical Air Command
TAS	true airspeed
TFW	Tactical Fighter Wing
WRCS	weapons release computer set

LIST OF TECHNICAL NOTES

Number	Title	Date
76-1	(Number not used)	
76-2	Some Aspects of Estimating the Probability of Cloud-Free Lines-of-Sight in Dynamic Situations (AD-A070154)	Mar 76
76-3	Model Output Statistics Forecast Guidance (AD-A037148)	Sep 76
77-1	Listing of Seminars Available from Hq AWS, AWS Wings, and AFGWC	Mar 77
77-2	USAFETAC Data Base Handbook (AD-A061955)	Jun 77
77-3	Soil Moisture Agrometeorological Services (AD-A047760)	Jun 77
77-4	The Impact of Winds-Aloft Errors on Air-to-Ground Ballistic Ordnance Deliveries (AD-)	Jun 77

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